THE UNIVERSITY OF MICHIGAN

College of Engineering
Department of Engineering Mechanics
Meteorological Laboratories

Technical Progress Report No. 3

RAIN SCAVENGING OF PARTICULATE MATTER FROM THE ATMOSPHERE

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APPENDIX A

INTRODUCTION

A substantial part of the work of the year was summarized in the report entitled "Rain Scavenging Studies" [1] which was prepared for the Autumn, 1961, Fallout Studies Conference at Germantown, Maryland. Activities that were omitted from that paper are presented below. Included are (1) rainfall climatology tables and graphs for the Willow Run rain sampling station; (2) results of collision efficiency computations specialized to the 2210 fluorescent powder used as a tracer in diffusion and scavenging experiments at the Hanford Atomic Products Operation diffusion course; and (3) a summarization of data gathered in experiments at the Hanford site during summer, 1961.

1. RAINFALL CLIMATOLOGY OF THE WILLOW RUN AIRPORT

Data from the U. S. Weather Bureau station at Willow Run Airport for the years 1948-1960 were used. The hourly rainfall statistics were summarized to form contingency tables (Tables 1-7) of total rain against mean hourly rainfall and to construct bar graphs (Figures 1-7) showing frequency of occurrence of several classes of hourly rainfall amounts by hour of the day. Summarizations for the months of June through December are presented here. The months of January through May are in process.

TABLE 1

JUNE, for years 1948-1960

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in. .10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01	1					1
0.01-.019	11	2	1			14
.02-.029	5	3				8
.03-.039	5	3				8
.04-.049	3	3				6
.05-.10	17	13	8	3		41
.11-.20		7	5	1		13
.21-.30		1	1			2
.31-.40		1		1		2
Σ	42	33	15	5		95

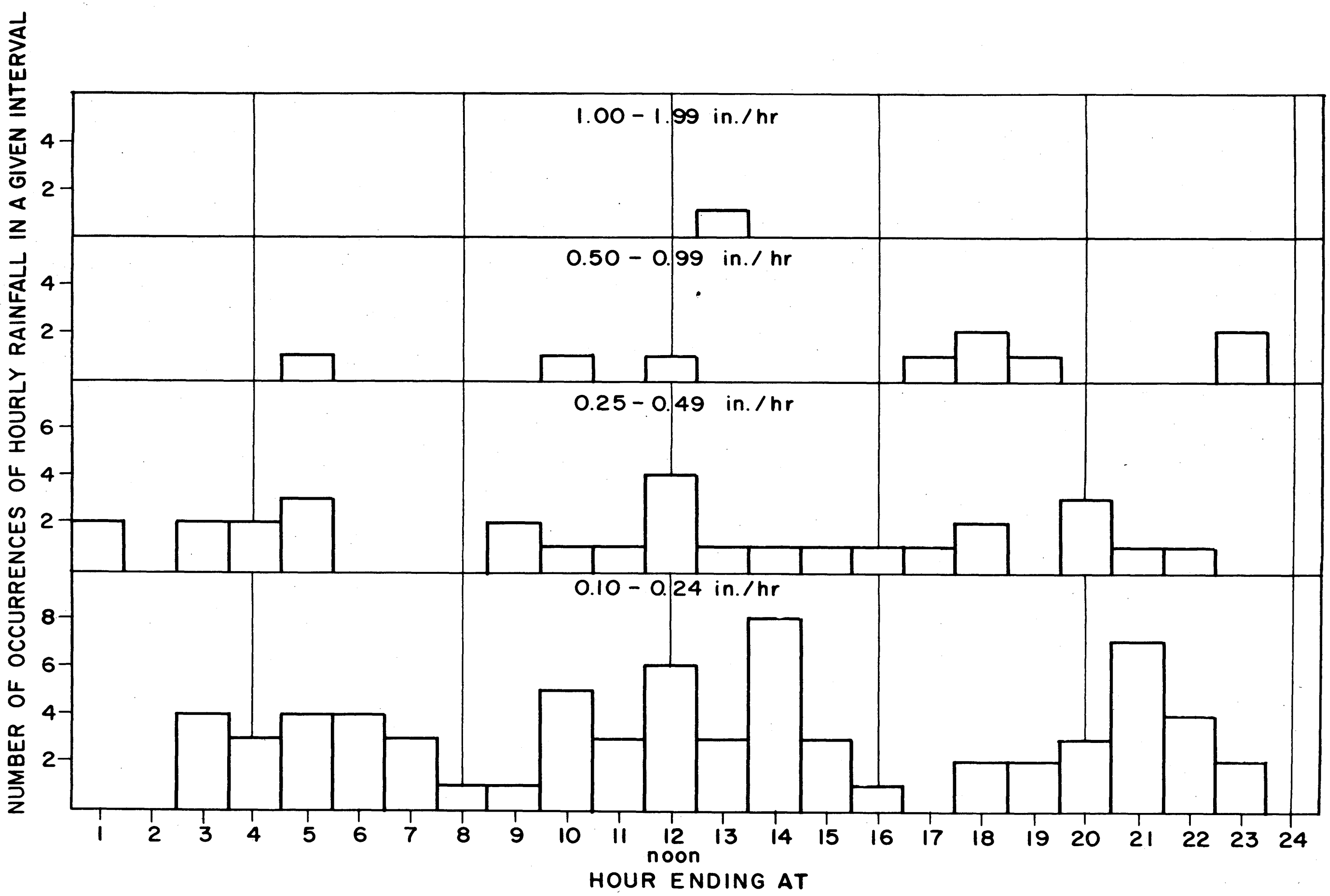

Figure 1. Month of June.
Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, from U. S. Weather Bureau Station, Willow Run Airport.

TABLE 2

JULY, for years 1948-1960

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in.					
	.10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01	1					1
0.01-.019	4					4
.02-.029	7	1	1			9
.03-.039	6	2				8
.04-.049	3	1	2			6
.05-.10	8	13	2	1		24
.11-.20	3	5	4	4		16
.21-.30	1	1	2	2	1	7
.31-.40			1	1		2
.41-.50				1		1
.51-.60						
.61-.70						
.71-.80			1			1
Σ	33	23	13	9	1	79

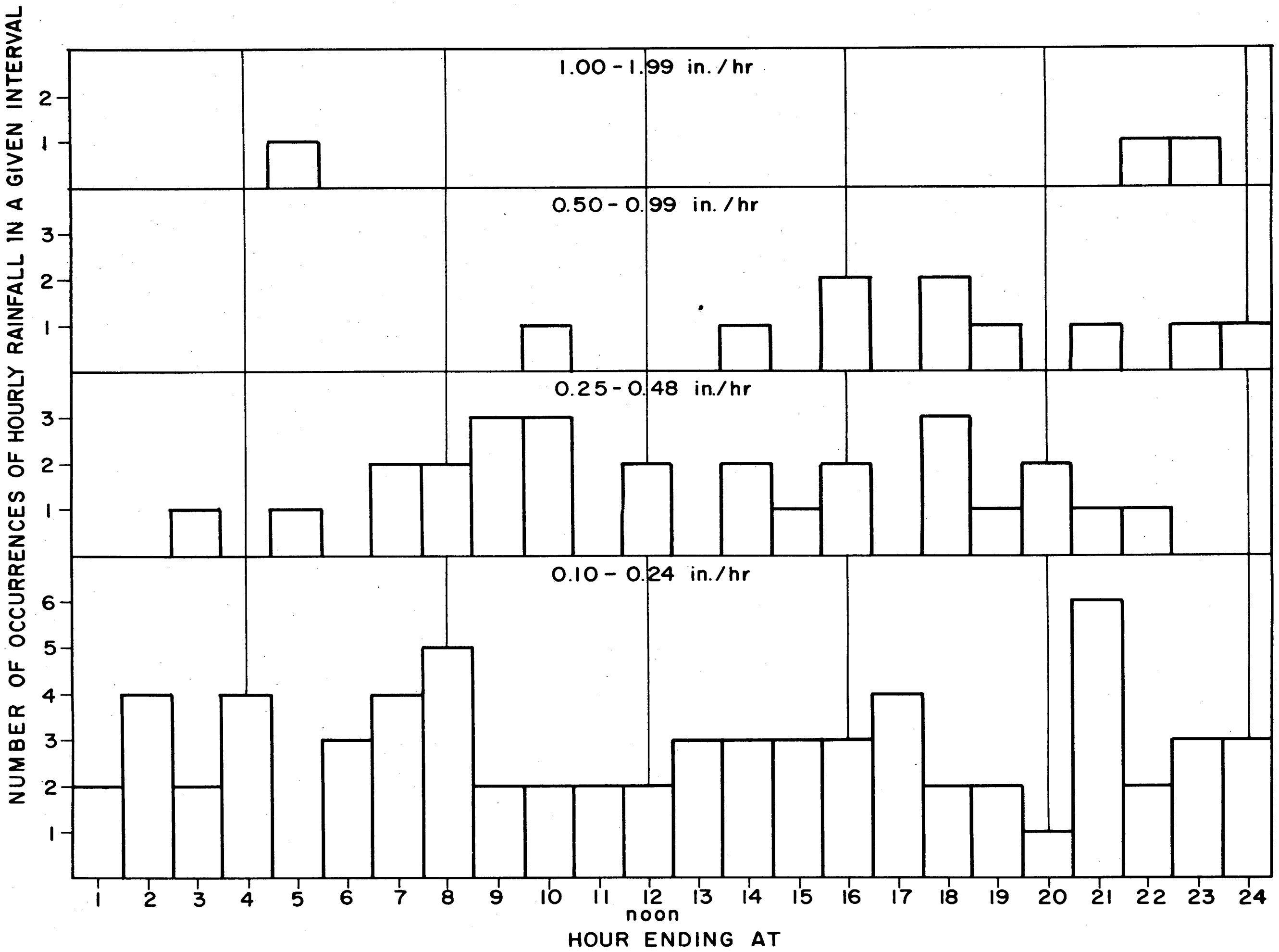

Figure 2. Month of July.
Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, from U. S. Weather Bureau Station, Willow Run Airport.

TABLE 3

AUGUST, for years 1948-1960

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in.					
	.10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01						
0.01-.019	5		3			8
.02-.029	3	4				7
.03-.039	6	3				9
.04-.049	1	4				5
.05-.10	13	7	2	1		23
.11-.20	3	7	7	1		18
.21-.30			1	2		3
.31-.40					1	1
.41-.50		1	1			2
.51-.60			1			1
Σ	31	26	15	4	1	77

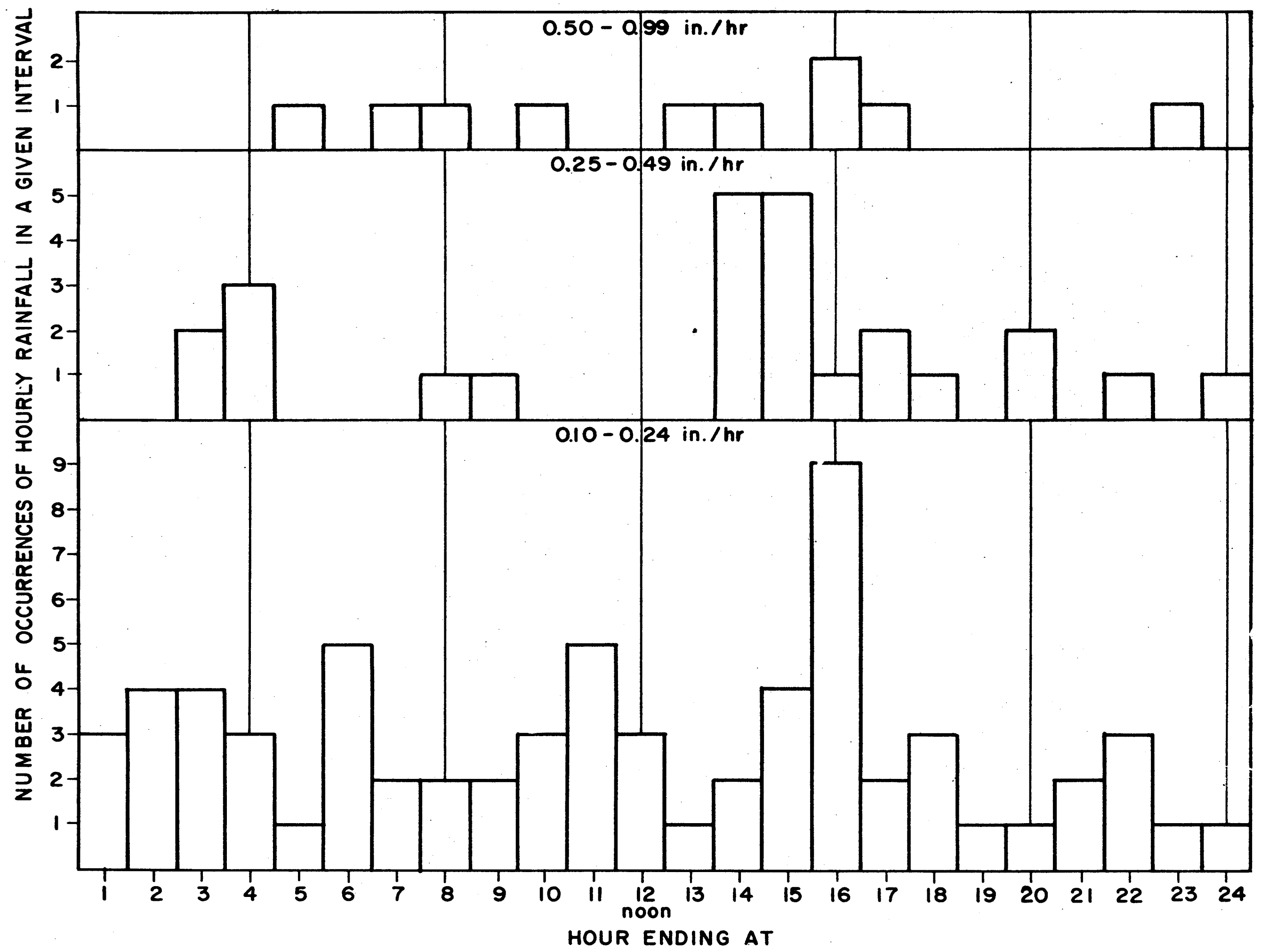

Figure 3. Month of August.
Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, from U. S. Weather Bureau Station, Willow Run Airport.

TABLE 4

SEPTEMBER, for years 1948-1960

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in.					
	.10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01						
0.01-.019	2	2				4
.02-.029	5	2				7
.03-.039	3	4	1			8
.04-.049	2	2	1			5
.05-.10	5	7	3	3		18
.11-.20	1	3	3			7
.21-.30	1		2	2		5
.31-.40				1		1
Σ	19	20	10	6		55

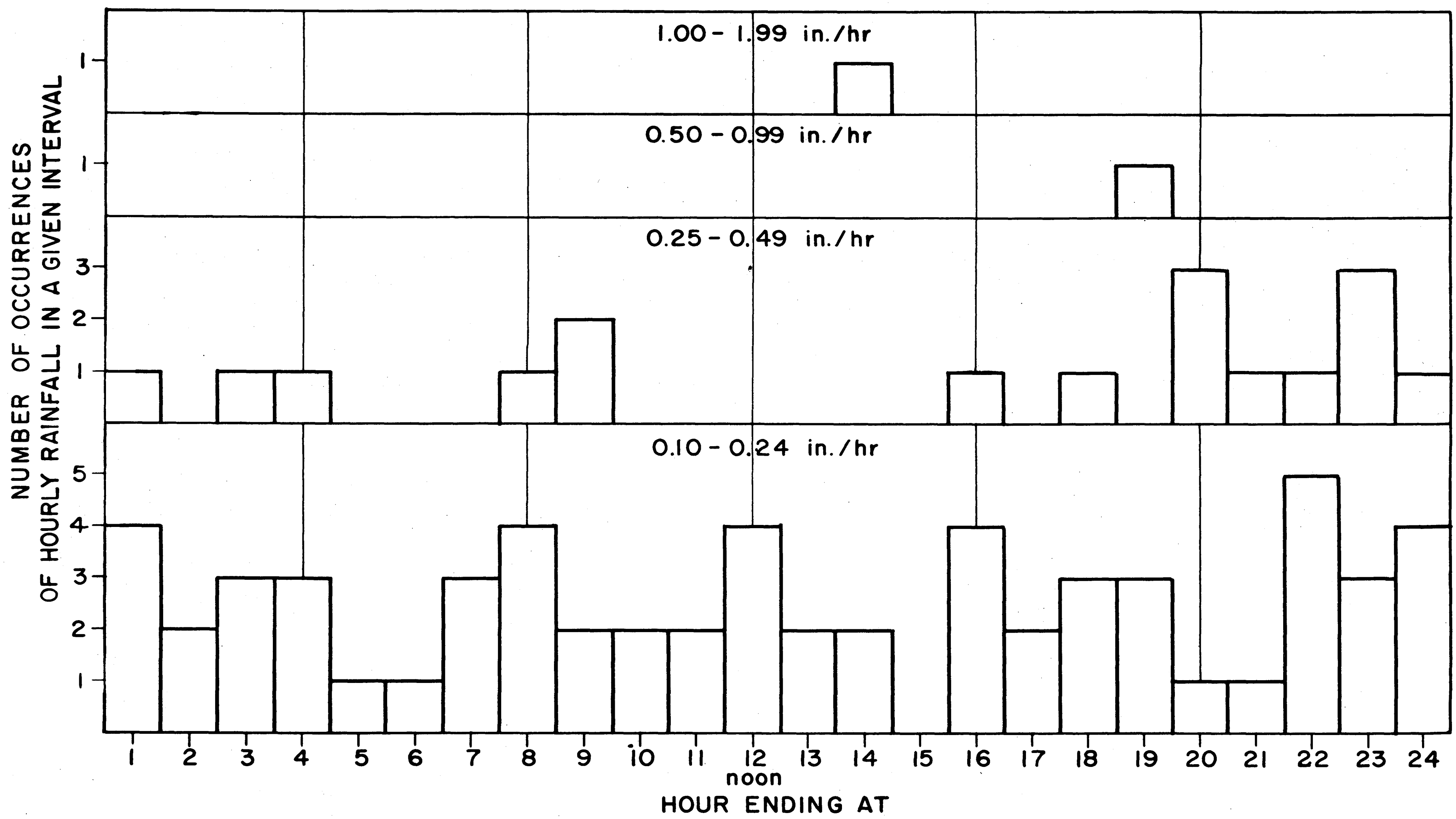

Figure 4. Month of September.
Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, from U. S. Weather Bureau Station, Willow Run Airport.

TABLE 5

OCTOBER, for years 1948-1960

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in.					
	.10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01						
0.01-.019	2					2
.02-.029	4					4
.03-.039	5					5
.04-.049	5	3		1		9
.05-.10	8	8	5	3	1	25
.11-.20	3	6	1	2	2	14
.21-.30	1	1	1	1		4
.31-.40						
.41-.50					1	1
Σ	28	18	7	7	4	64

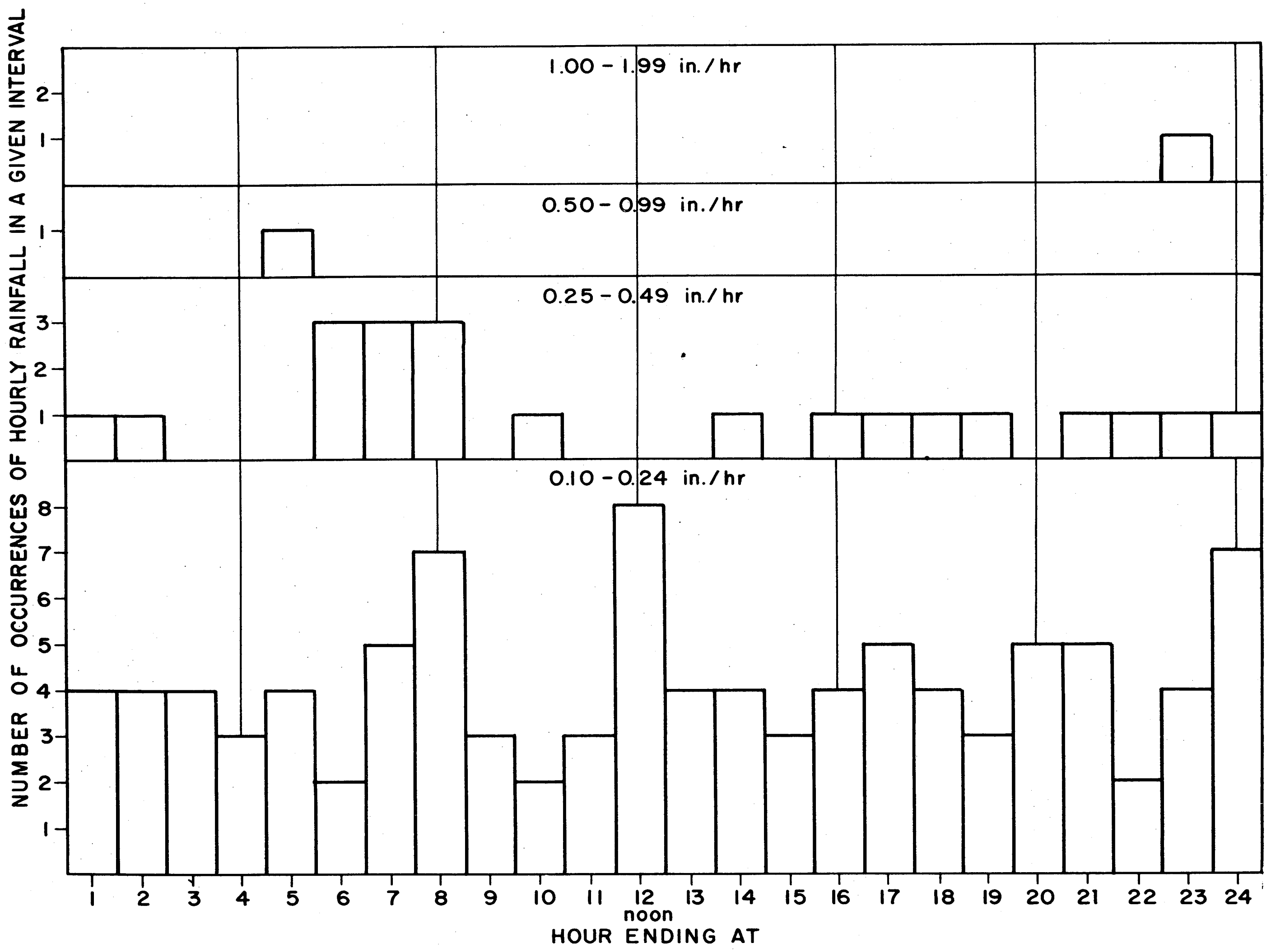

Figure 5. Month of October.
Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, from U. S. Weather Bureau Station, Willow Run Airport.

TABLE 6

NOVEMBER, for years 1948-1960
(1952 missing)

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in.					
	.10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01	2	2				4
0.01-.019	5					5
.02-.029	13	2	2			17
.03-.039	6	3	2	1		12
.04-.049	2	2	1	1	1	7
.05-.10	6	4	2	6		18
.11-.20		2	1			3
Σ	34	15	8	8	1	66

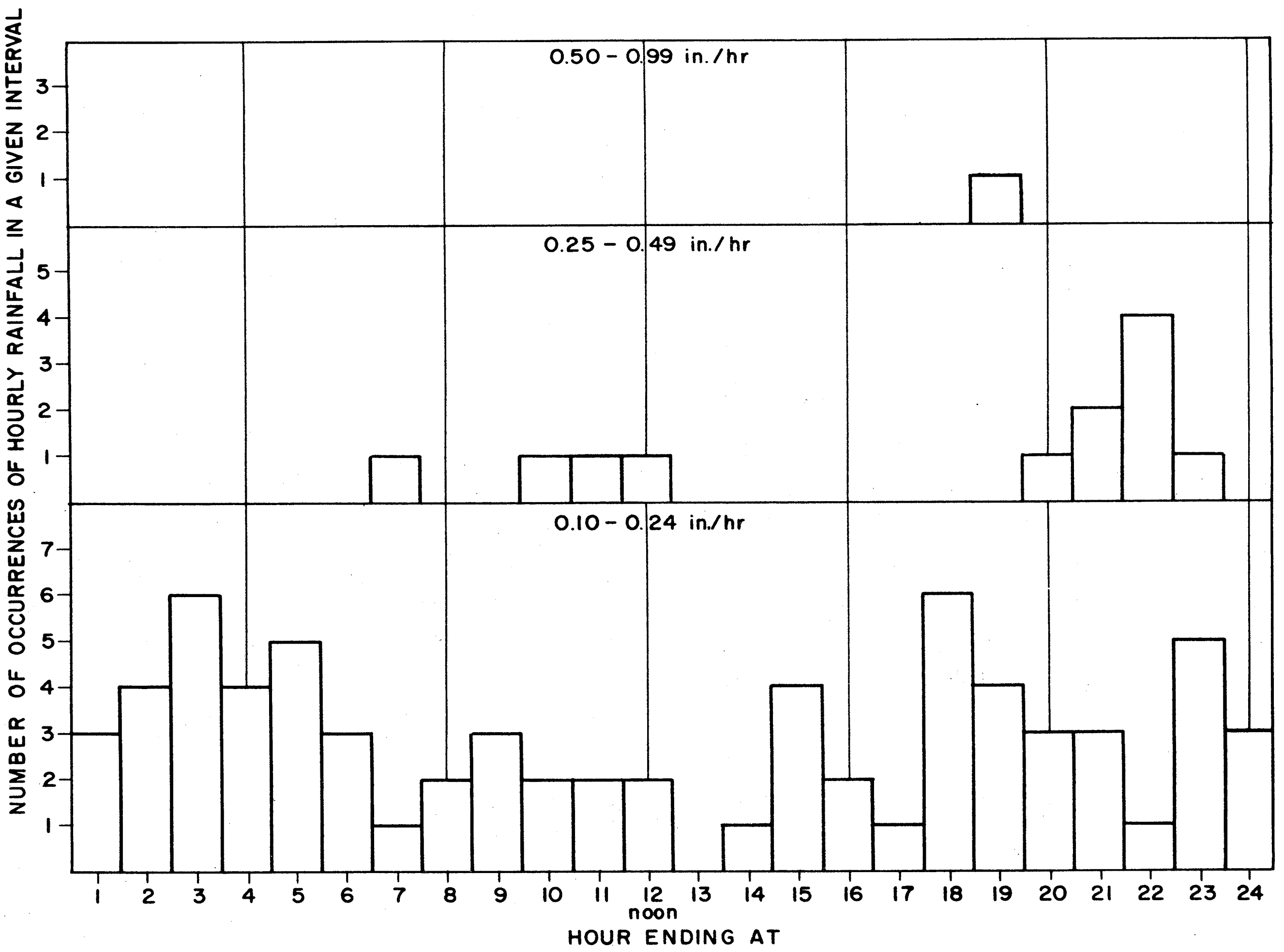

Figure 6. Month of November.
Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, except 1952, from U. S. Weather Bureau Station, Willow Run Airport.

TABLE 7

DECEMBER, for years 1948-1960

Contingency Table - Number of occurrences of specified mean hourly rainfall per shower of specified total rainfall.

Mean Hourly Rate in./hr	Total Rainfall During Shower, in.					
	.10-.24	.25-.49	.50-.99	1.00-1.99	2.00+	Σ
< 0.01	3					3
0.01-.019	14	2				16
.02-.029	5	3	3			11
.03-.039	2	8	4	3		17
.04-.049	1	2	2			5
.05-.10	1	4	3	2		10
.11-.20		1	2			3
Σ	26	20	14	5		65

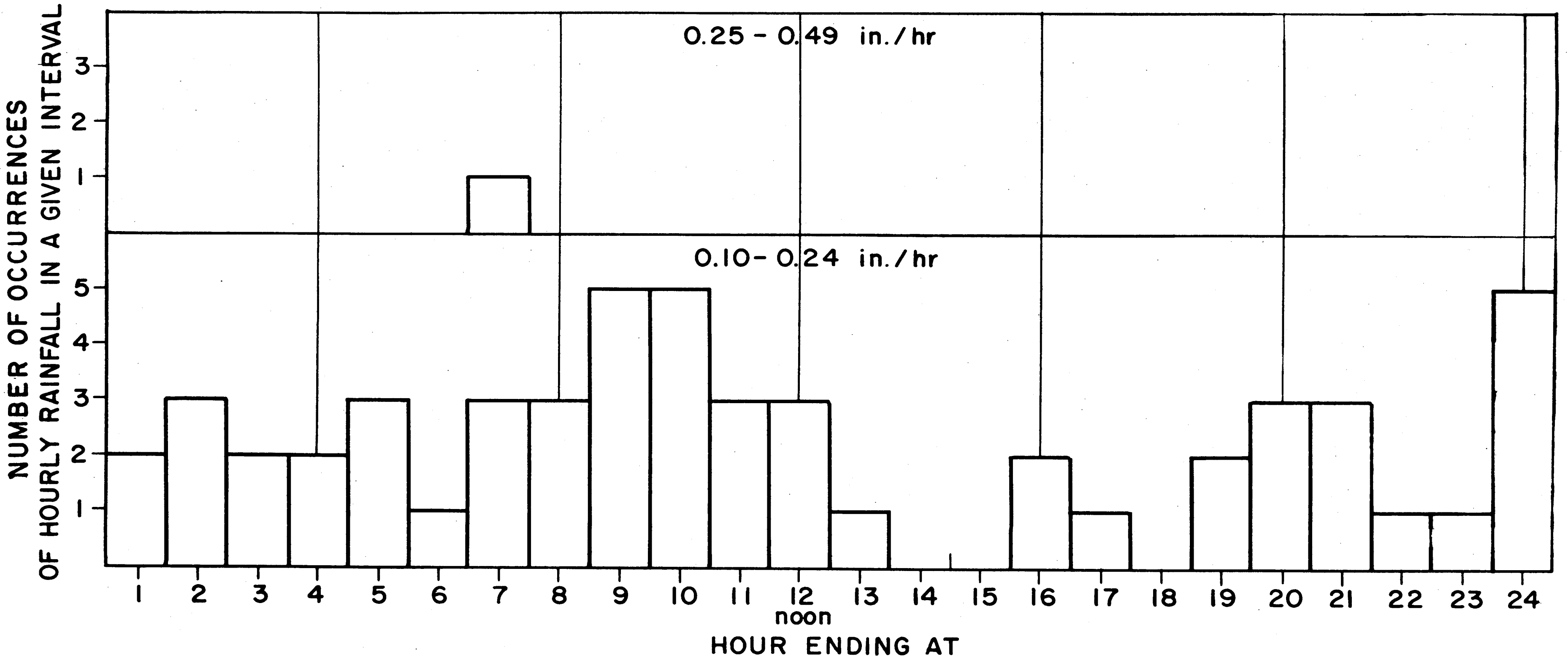

Figure 7. Month of December. Frequency of occurrences of hourly rainfall amounts by hour of day. Data for 1948-1960, from U. S. Weather Bureau Station, Willow Run Airport.

2. COMPUTATIONS OF LANGMUIR COLLISION EFFICIENCIES

As a part of the work leading to computations within the context of existing scavenging theory, computer programs for calculating Langmuir collision efficiencies and Greenfield total scavenging effectiveness were developed in the MAD (Michigan Algorithmic Decoder) language. The first of these has been checked quite thoroughly, and is presented below (p. 38) together with a brief discussion of the Langmuir equations. The second needs further work before it is ready for publication.

These computer programs are designed to use the data output from the raindrop-size spectrometer for calculating the scavenging effectiveness of observed rains under assumed or measured air pollution situations. Data from the spectrometer are reported in 24 size classes at 200-μ intervals from 0 to 4800μ diameter. Results of the collision efficiency calculations for the effect of rain falling through a cloud of 2210 f.p. material are presented in Table 8. The curve of collision efficiencies of rain on airborne ragweed pollen of 20-μ diameter and density of 1.3 gm/cm^3 is shown in Figure 8.

3. FIELD EXPERIMENTS AT HANFORD APO DURING SUMMER 1961

The principal objective of the cooperative field experiments conducted by this group and the Hanford group during the summer of 1961 was to perform a series of tracer scavenging experiments using the Hanford diffusion course

TABLE 8

Langmuir Collision Efficiencies in Per Cent
for Water Drops on Particles of Density 4.10 g/cm^3

Water Drop Diameter in MM	Particle Diameter in Microns						
	1.5	2.2	3.1	4.3	6.1	8.6	12.2
0.2	1.19	3.08	5.66	18.88	42.25	59.41	72.93
0.4	4.27	10.56	18.63	36.33	56.24	70.49	81.03
0.6	6.49	15.96	28.00	46.20	64.38	76.95	85.69
0.8	7.69	18.96	33.34	51.58	68.89	80.55	88.30
1.0	8.28	20.52	36.26	54.52	71.39	82.57	89.79
1.2	8.24	20.73	37.13	55.36	72.24	83.38	90.44
1.4	7.98	20.42	37.15	55.39	72.43	83.67	90.73
1.6	7.66	19.92	36.78	55.06	72.31	83.73	90.86
1.8	7.32	19.33	36.21	54.54	72.01	83.64	90.88
2.0	6.98	18.69	35.50	53.88	71.58	83.44	90.82
2.2	6.70	18.16	34.91	53.33	71.21	83.27	90.77
2.4	6.41	17.59	34.21	52.67	70.74	83.02	90.66
2.6	6.08	16.90	33.31	51.78	70.08	82.63	90.47
2.8	5.74	16.17	32.32	50.79	69.32	82.17	90.23
3.0	5.43	15.50	31.39	49.85	68.58	81.72	89.98
3.2	5.12	14.81	30.42	48.85	67.77	81.21	89.70
3.4	4.83	14.16	29.45	47.87	66.95	80.68	89.41
3.6	4.56	13.53	28.51	46.88	66.11	80.14	89.11
3.8	4.29	12.88	27.52	45.81	65.20	79.54	88.76
4.0	4.04	12.28	26.57	44.76	64.29	78.94	88.42
4.2	3.81	11.69	25.63	43.71	63.37	78.31	88.06
4.4	3.57	11.11	24.68	42.61	62.39	77.64	87.67
4.6	3.36	10.56	23.76	41.53	61.42	76.97	87.27
4.8	3.16	10.04	22.87	40.47	60.44	76.29	86.86

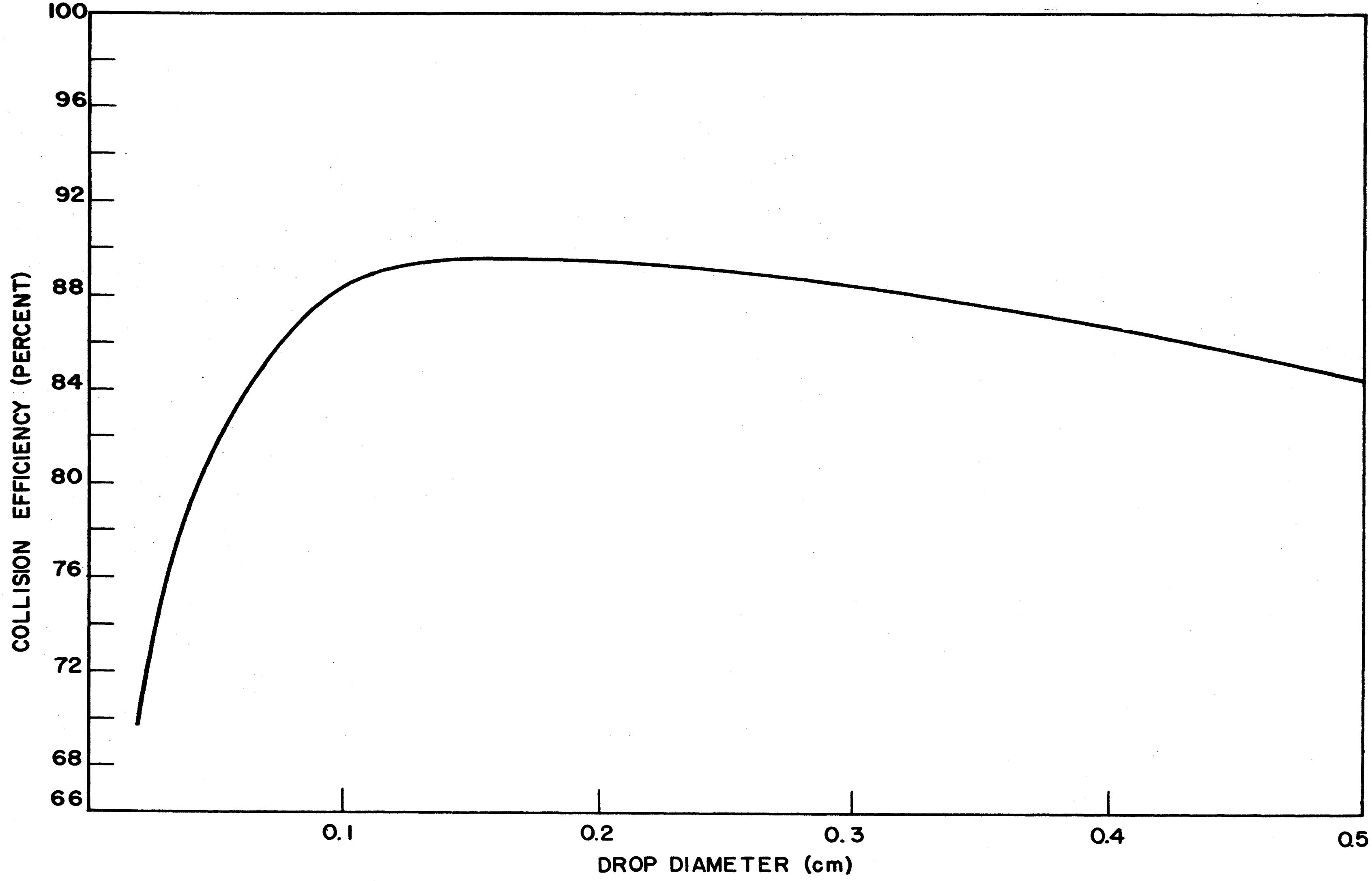

Figure 8. Langmuir collision efficiencies for raindrops on ragweed pollen (20µ diameter, 1.3 gm/cm^3 density).

facilities in addition to some of the instrumentation developed here and at Hanford for rain scavenging research. It was recognized in advance that the weather conditions on the Hanford site would not provide natural rain for our experiments, hence we planned to use an artificial spray for all of the studies in this series. The general design of the experiments was that fluorescent powder would be put into the air by the aerosol generator used for the Hanford diffusion experiments, and that the artificial rain would fall through the plume of contaminant achieving terminal velocity at a considerable height above the ground, and being sampled at or near ground level. The fluorescent powder used was 2210-grade ZnS which has particles ranging in diameter from less than 1μ to over 10μ, and which tends to behave as a nonwettable material [2]. This experimental design permitted us to do the experiments that we wanted to do on accretion in conjunction with the regularly run diffusion experiments of the Hanford group without serious disturbance to their regular program of diffusion studies.

a. Installation of Equipment.

It was decided that the artificial spray needed for the proposed experiment should be installed at the top of one of the 90 ft poles in the 200 meter arc of the Hanford diffusion course. The particular pole chosen was selected after a careful study of the low level air flow from the generator site to the 200 meter arc under the stable nighttime conditions required for the experiment. These evaluations were done primarily by Mr. Engelmann.

On the basis of preliminary studies of the trajectories taken by the water drops from this spray, the position of the raindrop-size spectrometer was chosen. Preparations for the installation of the spectrometer on the diffusion course included the laying of a concrete slab to serve as a base for the spectrometer. Upon arrival at the station, the University of Michigan personnel installed the spectrometer itself and the light shield surrounding it.

Preliminary experiments had indicated that whereas the spectrometer would be capable of measuring the drop sizes of drops that fell into its detection area, the bulk water sampling procedure necessary to catch rain and evaluate its accretion of 2210 material would not be entirely satisfactory for the purpose before us. Mr. Engelmann had independently developed a sampling technique based upon the use of a continuous strip of diazo paper which made it possible not only to measure the drop sizes in the small drop range (below about 1.8 mm diameter), but also to identify with each drop the specific 2210 particles brought down by that drop. For the conditions of the experiment this particular instrument was quite ideal for the small drop range. Because it was desired also to identify the particulate accretion of the larger drops, another sampler designed to use large sheets of diazo paper and intermittent sampling was developed during the course of the experiment.

b. Operations

The experiments were run in the pre-dawn hours according to the custom developed by the Hanford group.

The decision whether to schedule an experimental run was made and the appropriate personnel were alerted by the Hanford staff people ordinarily charged with this responsibility. The success of an experiment depended almost completely upon the direction that the lowest level wind took between about 3:30 a.m. and 6:30 a.m. Although we had good wind indicating equipment immediately adjacent to the experimental area, it was quite difficult to tell whether the plume of particulate material was indeed centered on the rain accretion experiment. Under the stable conditions chosen for the runs the wind tended to be very light and to meander somewhat, and as a result, only the experiment of August 24, 1961, provided a good contaminant plume "on course." In this case the plume was carried quite directly over the experimental area, for a period of several minutes.

c. Results

The count of 2210 material picked up by the filters on the 90 ft pole are given in Table 9. The results obtained by Mr. Engelmann using his apparatus, when summed over all drop sizes sampled, apparently fall well below the theoretical curve obtained by the use of Langmuir's collision efficiency values, and look similar to the data of McCully. These results are however limited to the drop sizes below 1.8 mm diameter, and they apply to 2210 particles on the order of 2 to 35 microns in diameter. At the upper end of the particle size range, the efficiency appears suddenly to increase. Additional data are needed for larger particle sizes. Because 2330 and 2210 dusts are both ZnS, it is difficult to

TABLE 9

Vertical profile of the plume of 2210 ZnS as shown by millipore filters on the 90 ft pole on which the artificial water spray was mounted: 200 m from generator, 7 m upwind from the spectrometer, 10 to 50 m upwind from continuous diazo sampler (Engelmann).

Height, m	Surface	.34	.68	1.35	1.50	2.70
# of particles x 10^{-3}	70	79	106	110	155	161

Height, m	4.05	5.40	6.75	8.10	9.45	10.80
# of particles x 10^{-3}	160	135	144	93	52	12

Height, m	13.50	16.2	18.9	21.6	24.3	27.0
# of particles x 10 ^{3}	2	.3	.46	.059	.021	.034

understand the separate curves McCully, et al, reported [2]. It is apparent that more evidence must be obtained.

For the larger drops up to the order of 6 mm diameter, it was necessary to use the diazo sheet sampler, and the results from these samples are less well defined. Problems of splash of the large drops and of an excess of water which tended to flow across the sampling sheets, made the interpretation of these samples very difficult.

A few good samples were obtained and some analysis of these has been made. Diagrams showing the stain shapes and sizes at full scale and showing the counts of f.p. material found in the stains formed by 22 drops, are reproduced in Figures 9 and 10. The diameters of the drops that made these stains have been estimated in the following way: (1) the area of each stain was measured using a planimeter, (2) the diameter of the area-equivalent circle was computed, and (3) this "equivalent stain diameter" was used to determine the estimated raindrop diameter from the calibration curve for the diazo paper (Figure 12). Results of this procedure are given in Table 10, and a scatter diagram showing the number of 2210 particles captured against the estimated drop diameter is shown in Figure 11. The substantial scatter is attributed principally to the variable density of the contaminant cloud due to meander of the plume at the sampling site. Despite this effect, there is an obvious correlation of drop size with particle capture. A particle-size analysis of the f.p. material captured by the large drops is given in Table 11.

The present data are especially important because observations on the basis of individual drop sizes are avail-

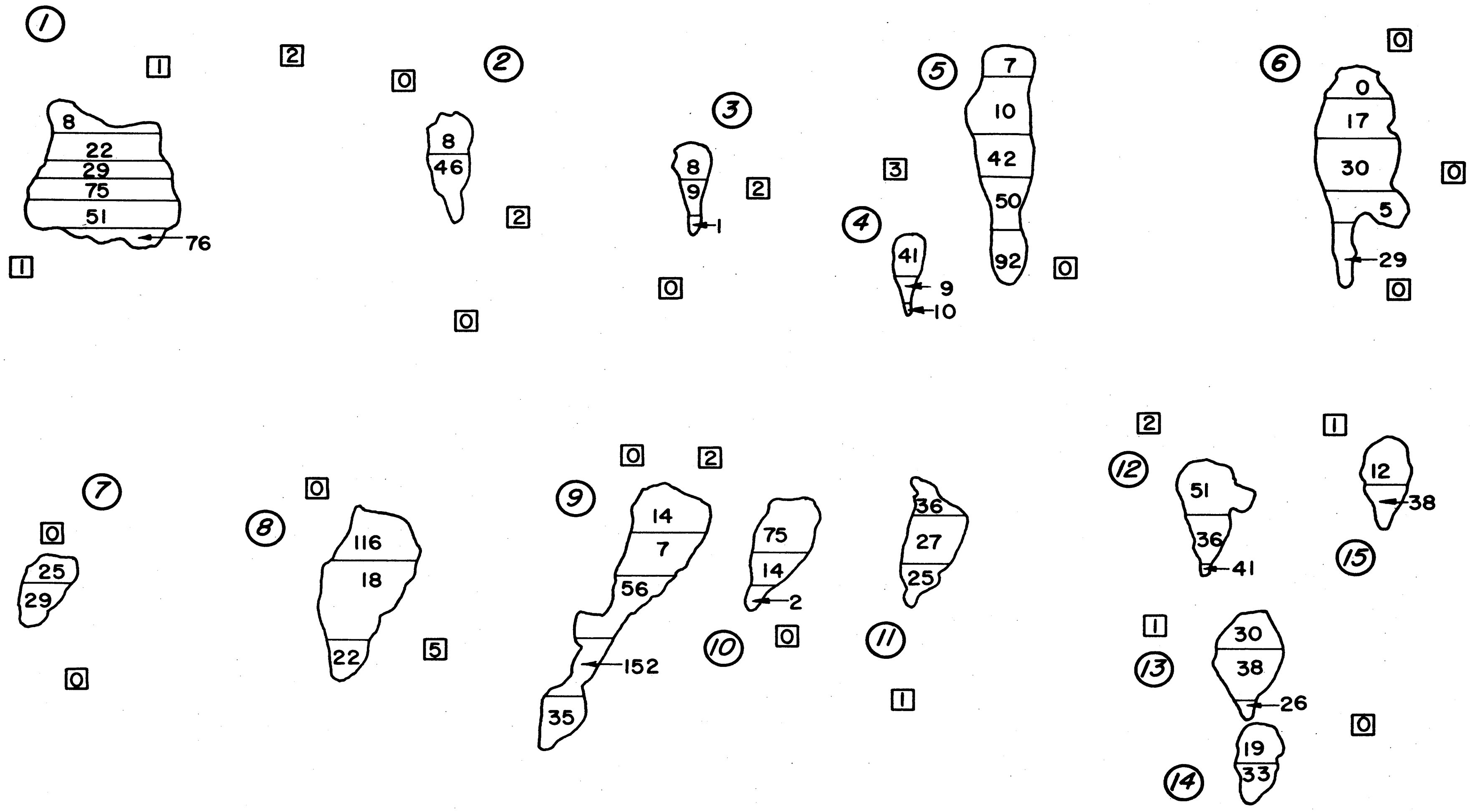

Figure 9. Large drop stains, traced from diazo sheets exposed at 0529 PST. Drops identified by numbers in circles, background counts given in squares, counts of particles captured given by counting fields drawn on the stains. Additional data given in Table 10.

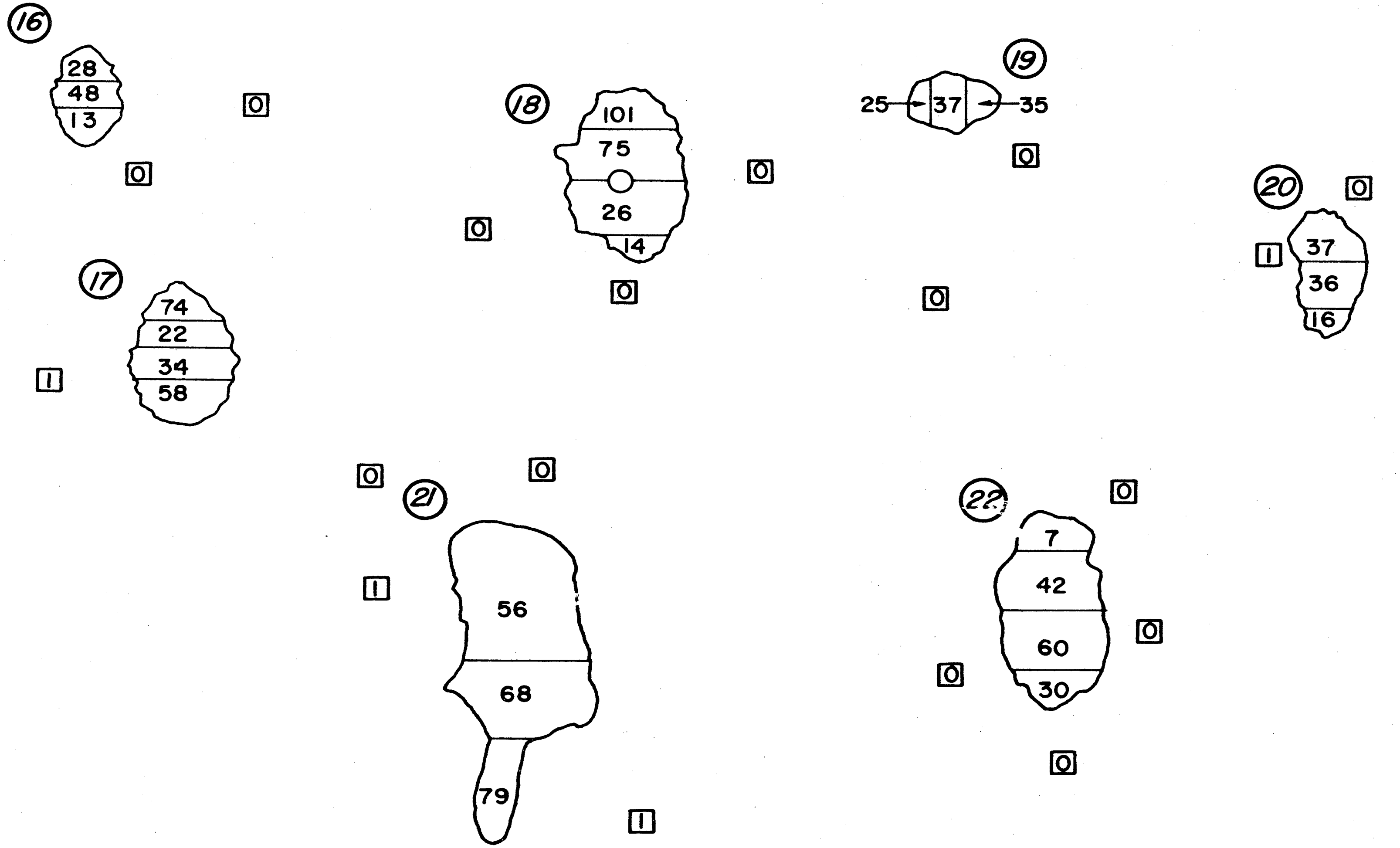

Figure 10. Large drop stains, traced from diazo sheets exposed at 0531 PST. Drops identified by numbers in circles, background counts given in squares, counts of particles captured given by counting fields drawn on the stains. Additional data given in Table 10.

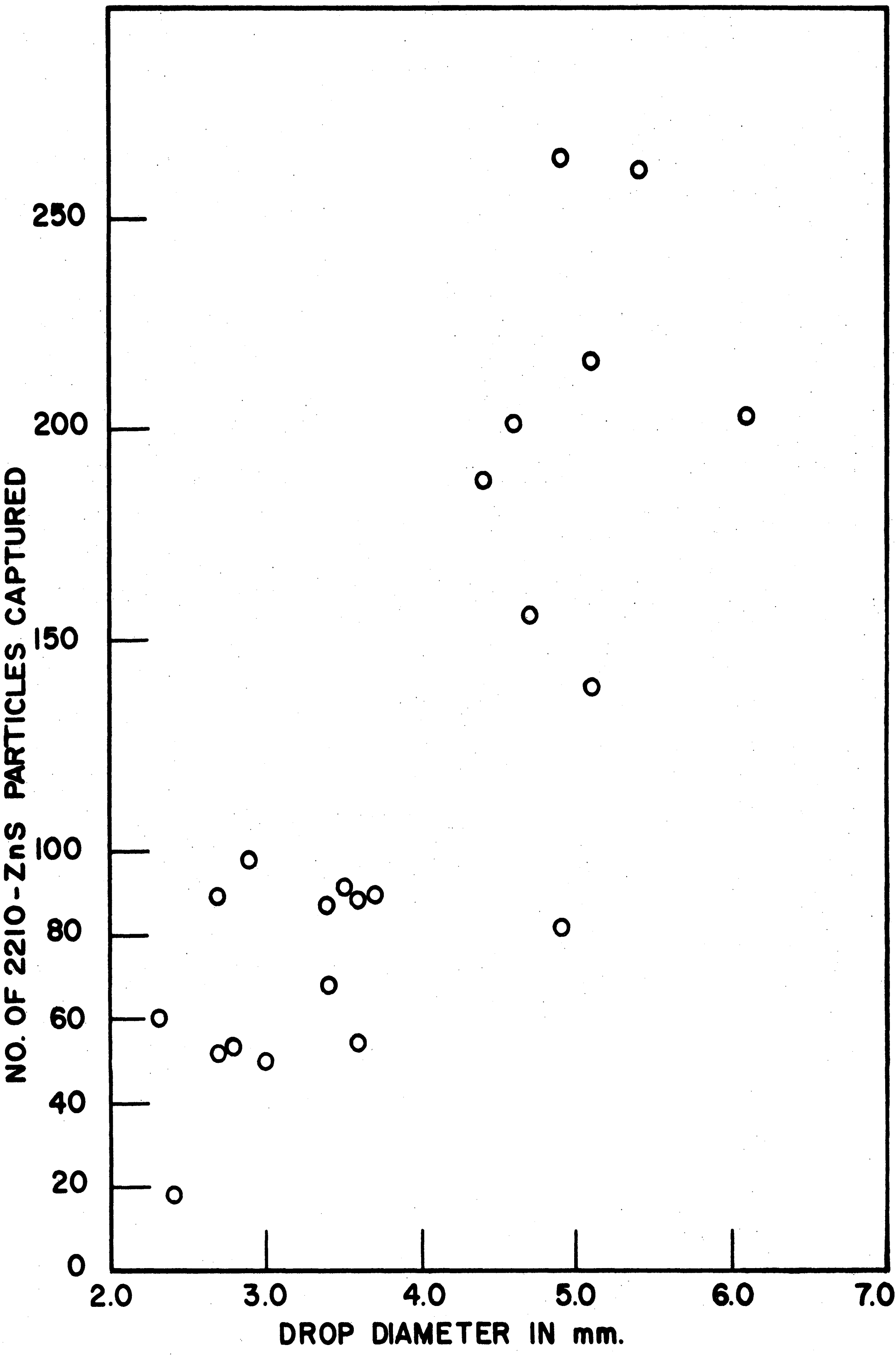

Figure 11. Scatter diagram showing observed relationship of drop size to number of particles captured.

TABLE 10

Tabulation of stain areas, equivalent drop diameters, and total of particles captured by the large drops.

Diazo Sheet #	Drop #	Area in.^{2}	Equiv. Diameter mm	Est. Equiv. Drop Diameter mm	Total Particles Captured
W 13	1	1.12	30.07	5.4	261
	2	0.28	15.14	3.3	54
	3	0.13	10.26	2.4	18
	4	0.11	9.50	2.3	60
	5	0.74	24.64	4.6	201
W 14	6	0.85	26.47	4.9	81
W 15	7	0.19	12.45	2.8	54
	8	0.77	25.15	4.7	156
	9	0.84	26.26	4.9	264
	10	0.35	16.97	3.5	91
	11	0.37	17.48	3.6	88
	12	0.31	16.00	3.4	87
	13	0.31	16.00	3.4	68
	14	0.18	12.14	2.7	52
	15	0.22	13.46	3.0	50
R 9	16	0.18	12.14	2.7	89
	17	0.65	23.11	4.4	188
	18	0.91	27.38	5.1	216
	19	0.20	12.85	2.9	97
	20	0.41	18.39	3.7	89
R 12	21	1.60	35.61	6.1	203
R 10	22	0.94	27.79	5.1	139

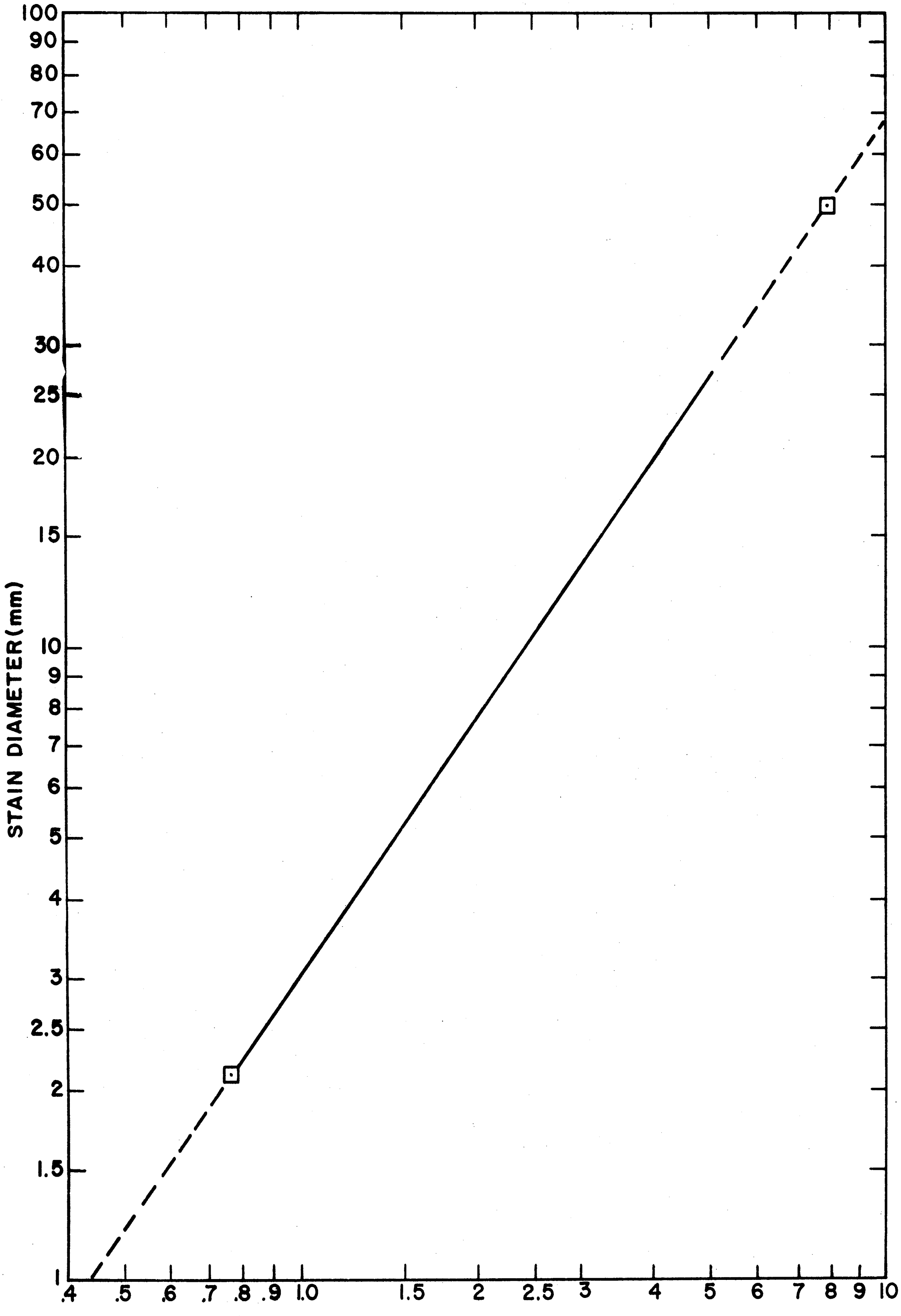

Figure 12. Calibration curve relating stain diameter on diazo paper to diameter of water drop falling at terminal speed in still air.

able thus providing a more adequate basis for the experimental study of the accretion process than has been available heretofore.

TABLE 11. Particle size analysis for 2210 material found in large drop stains: d is diameter of upper limit of size class.

d in microns	3.51	4.24	6.00	8.485	12.00	16.965	24.00	33.935
n	0	28	27	40	32	12	6	1

d. Conclusions

1. Further study of these data in the light of existing accretion theories will be made. This has not been done prior to the present report primarily because of a shortage of funds.

2. A more complete experimental evaluation of the accretion effect is needed, especially for the larger drop sizes and for larger particles of ZnS. Field experiments, however, should probably be postponed until more complete laboratory evaluations can be made.

3. Laboratory work can be done in the separate laboratories at Hanford and at The University of Michigan, to establish a more firm background of design data from which to project ultimate field experiments under natural rain. We anticipate entering into this laboratory phase of work during the coming year. Whereas it is recognized that the experimental work of Oakes [3] and the theoretical

work of Pemberton [4] are pertinent to our problems, the particle-size spectra and drop-size spectra that they have considered are not broad enough for our purposes.

4. Eventual field experiments should be planned for areas and seasons of adequate rainfall. The experiments at the Hanford site have contributed a good deal of information, and further experiments of this sort should be done at a future time. These will be designed on the basis of the projected laboratory work. In addition it is necessary that field evaluations under various natural rains be made. A number of possibilities are obviously available to us, and specific plans will be prepared and proposals made at a future date.

5. In addition to the experimental studies, it is important that theoretical studies be done. In the present data there exist difficulties in terms of precisely equivalent timing between the filter samples taken to evaluate the plume (throughout the run) and those taken from the rain falling through the plume. It is desirable that the experimental findings should be resolved as well as possible with existing theory and that refinements of the theory be developed. In particular, the effects of raindrop-generated turbulence of very small scale, observed by Oakes [3], may prove to be quite significant in the scavenging-accretion-washout processes.

4. FALL AND WINTER SEASON DATA COLLECTION AT HANFORD.

The raindrop-size spectrometer was left on the Hanford diffusion site when the University of Michigan crew returned home last summer. The idea of doing this was to make available to the collaborating group the drop sizes of natural rains occurring at the Hanford site in conjunction with which Mr. Engelmann proposed to collect samples of scavenged material. At the date of this writing the raindrop-size spectrometer is still in the field at that site, and is to be returned to Michigan soon. An interesting by-product of the study, made possible by having the raindrop spectrometer there, is a set of data on snow. During a light snow typical of the Hanford area in winter, the raindrop-size spectrometer was operated and the diazo sampler was also operated to determine the accretion and scavenging effectiveness of the falling snow. It turns out that the diazo sampler is capable of giving a fair image of the individual snow crystals, so that one may be able to identify quite well whether they are plates of prisms or dendritic type crystals. With these data and the pulse height data accumulated by the spectrometer it is anticipated that a calibration curve for snow can be developed to interpret the raindrop-size spectrometer pulses. Although this development is not immediately pertinent to the problems of rain scavenging of radioactive particulates, it is of obvious interest for the question of snow scavenging.

The data are as yet too fresh to have been analyzed in any quantitative way, so they are not presented in this report.

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APPENDIX A

LANGMUIR COLLISION EFFICIENCIES

In studying the coalescence and accretion processes in the growth of raindrops, Langmuir [1] analyzed a physical model of a large drop sweeping through a space occupied by smaller droplets. He noted that by virtue of the deflection of the streamlines near the large drop, some small droplets would be deflected, but that by virtue of their inertia, the small droplets would tend to cross streamlines to a certain extent, varying with their size. His solution is based on the trajectory of the center of the small droplet that just grazes the large drop. The relative velocities are determined from the equation for terminal velocity of spheres in air at 785 mb, +2°C, in which the frictional force

$$f = 6 \pi \eta r v(C_D R/24)$$

is equated with the gravitational force. Here η is the viscosity of the air, r is the radius of the spherical drop, v is its velocity, C_D is its drag coefficient, and R is the Reynolds number, defined by

$$R = 2 \rho r v/\eta$$

where ρ is the density of the air.

The collision efficiency is defined as the ratio of the actual collision cross section of the drop upon the droplet field to the geometric cross section of the drop.

Inasmuch as the flow pattern around a sphere, accounting for both inertial and viscous forces, has not been solved, some difficulty arises in determining the trajectories. Stokes' solution is available on the one hand (viscous flow) and on the other the solution for potential flow is known. Defining the parameter

$$K = \frac{2\rho}{9\eta} \frac{a^2}{r} (V - v)$$

where small droplets of radius a, moving at speed v, are considered in relation to large drops of radius r and fall speed V, and assuming that the flow about the large drop conforms to the solution for potential flow while the droplets' motion is controlled by viscous forces, the collision efficiency

$$E_p = K^2/(K + \tfrac{1}{2})^2 \quad \text{for} \quad K > 0.2$$

and

$$E_p = 0 \quad \text{for} \quad K < 0.0833$$

according to Langmuir.

If the viscous flow regime prevails about the drop, the collision efficiency is

$$E_v \doteq [1 + (0.75 \ \ell n \ 2K)/(K - 1.214)]^{-2}$$

except when $K < 1.214$, when $E_v = 0$.

On the basis of experimental findings, Langmuir then devised the interpolation formula:

$$E_L = [E_v + E_p R/60]/[1 + R/60]$$

which gives the "Langmuir collision efficiencies" for the domain intermediate between E_p and E_v.

The MAD program (p 38) was devised to compute the Langmuir collision efficiencies for rain of measured drop-size distribution upon a cloud of particles of known size distribution and density. The symbols used and their meaning are tabulated below:

NU = viscosity coefficient for air

D(1)... = raindrop diameter class, subscripted

U(1)... = raindrop terminal fall speed, subscripted, values from Gunn and Kinzer [9]

R(1)... = raindrop Reynolds number, subscripted, calculated

RHO(1)... = density of particle of subscripted size class

SMALL D(1)... = particle diameter class, subscripted.

Modifications of the Langmuir computations to allow for the physical size of the droplets have been made by Das [2] and by Ludlam [3]. Fonda and Herne [4] have made more detailed calculations of the droplet trajectories, and Mason [5] presents a corrected table of collision efficiencies based largely upon these results.

The question of wettability or non-wettability of the particles renders the detailed corrections of Langmuir's calculations largely academic. McCully [6] first indicated the importance of this question, and Pemberton [7] has analyzed the accretion process for wettable and non-wettable particles.

Because one should expect to find various degrees of wettability, the problem is not yet resolved theoretically. Experiments such as those of Oakes [8] appear to hold the greatest promise of giving the necessary numerical guide lines.

REFERENCES

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3. Ludlam, F. H., 1951. Quart. J. Roy. Met. Soc. 77, 402.

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5. Mason, B. J., 1957. The Physics of Clouds, London, Oxford Univ. Press, p. 424.

6. McCully, C. R., et al., 1956. Ind. Eng. Chem. 48, 1512.

7. Pemberton, C. S., 1960. Scavenging action of rain on non-wettable particulate matter suspended in the atmosphere, in Aerodynamic Capture of Particles ed. by E. G. Richardson, Pergamon Press, p. 168.

8. Oakes, B., 1960. Laboratory experiments relating to the washout of particles by rain. ibid., p. 177.

9. Gunn, R. and G. D. Kinzer, 1949. J. Met. 6, 246.

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$  COMPILE MAD, EXECUTE, DUMP, PRINT OBJECT, PUNCH OBJECT
          RLANGMUIR COLLISION EFFICIENCIES
START      READ FORMAT LIST,NU,D(1)...D(25),U(1)...U(25),R(1)...R(25)
           VECTOR VALUES LIST=$E8.2/24F3.2/F3.2/18F4.1/7F4.1/14F5.1/11F5
          1.1*$
           PRINT FORMAT ALIST,NU,D(1)...D(25),U(1)...U(25),R(1)...R(25)
           VECTOR VALUES ALIST=$1H E10.2/1H 22F5.2/1H 3F5.2/1H 22F5.1/1H
          1 3F5.1/(1H 19F6.1)*$
           READ FORMAT PTCL,N,RHO(1)...RHO(N),SMALLD(1)...SMALLD(N)
           VECTOR VALUES PTCL=$I2/7F4.2/7E8.2*$
           PRINT FORMAT PTCLE,N,RHO(1)...RHO(N),SMALLD(1)...SMALLD(N)
           VECTOR VALUES PTCLE=$1H0I2/1H 7F8.2/1H 7E12.3*$
           THROUGH PART2, FOR I=1,1,I.G.N
           INTEGER I,J,N
           PRINT FORMAT PRTCL,SMALLD(I),RHO(I)
           VECTOR VALUES PRTCL=$51H2COLLECTION EFFICIENCIES FOR PARTICLE
          1S OF DIAMETER E12.3,12H AND DENSITY F5.2,6H GM/CC*$
           C=SMALLD(I).P.2*RHO(I)/(9.*NU)
           THROUGH PART1, FOR J=1,1,J.G.25
           K=(C*U(J))/D(J)
           X=R(J)/60
           WHENEVER K.LE.1.214
           EV=0.
           OTHERWISE
           EV=(1.+0.75*ELOG.(2.*K)/(K-1.214)).P.-2
           END OF CONDITIONAL
           EA=(K/(K+0.5)).P.2
           E=(EV+EA*X)/(X+1.)
           ESAV(J) = E
 PART1     PRINT FORMAT RESULT, D(J),E
           VECTOR VALUES RESULT=$17H DROP DIAMETER = F5.2,9H CM, E = F7.
          14*$
 PART2     PUNCH FORMAT EPUNCH, ESAV(1)...ESAV(25)
           VECTOR VALUES EPUNCH = $(10F7.4)*$
           DIMENSION D(25),U(25),R(25),RHO(10),SMALLD(10),ESAV(25)
           END OF PROGRAM
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